IPhR 2024: Second Round

STEM October Physics Club

August 22, 2024

§1 Questions

1. What is the correct expression for the conservation of energy law?

   a) $\Delta k + \Delta U + \text{Q} + \Delta E_{in} = \text{W} + T_{MT} + T_{ET} + T_{ER} + T_{MW}$

   b) $\Delta k + \Delta U + \text{W} + \text{Q} + \Delta E_{in} = T_{MT} + T_{ET} + T_{ER} + T_{MW}$

   c) $\Delta k + \Delta U + \Delta E_{in} = \text{W} + \text{Q} + T_{MT} + T_{ET} + T_{ER} + T_{MW}$

   d) $\Delta k + \Delta U + T_{MT} + T_{ET} + T_{ER} + T_{MW} + \Delta E_{in} = \text{W} + \text{Q}$

   Solution: c

2. A water flows in a tube with a cross-section changes from 10 cm^2 to 40 cm^2, in this change, the pressure of the water changes by 850 Pascals, what is the volume flow rate?

   a) 1346.6 cm^3/s

   b) 13.466 cm^3/s

   c) 134660 cm^3/s

   d) 0.13466 cm^3/s

   Solution: a

   Due to Bernolli's equation:

$$P_a + \frac{1}{2}\rho V_a^2 = P_b + \frac{1}{2}\rho V_b^2$$
$$\Delta P = \frac{1}{2}\rho(V_b^2 - V_a^2)$$
$$850 = \frac{1}{2} \times 1000(V_b^2 - V_a^2)$$
$$(V_b^2 - V_a^2) = 1.7$$

   According to the continuity equation:

$$a_i V_i = a_f V_f \Rightarrow V_a = \frac{a_a}{a_b} V_b = 4V_b$$

Hence

$$(V_b^2 - V_a^2) = 1.7 \Rightarrow (V_b^2 - 16V_b^2) = 1.7$$

$$15V_b^2 = 1.7 \Rightarrow V_b = 0.34m/s = 34cm/s$$

$$\text{volume flow rate} = V_b a_b = 34 \times 40 = 1346.6$$

3. Imagine you're on the Moon, where the acceleration due to gravity is only one-sixth of that on Earth. If you were to kick a football on the Moon with the same force, speed, and angle as you would on Earth, how far would the ball travel?

   a) The same distance as on Earth.

   b) One-sixth the distance.

   c) Six times the distance.

   d) Thirty-six times the distance.

   Solution: c

4. Consider a system of the points $m_1 = 2kg$ at (1,2), $m_2 = 3kg$ at (4,-1), and $m_3 = 5kg$ at (-2,3). What are the coordinates for the center of mass of the system?

   a) (0.4, 1.6)

   b) (-1.6, 0.4)

   c) (-0.4, -1.6

   d) (1.6, 0.4)

   Solution: a

5. Which type of equilibrium is associated with the potential energy function $U(x)$ having a maximum?

   a) Stable equilibrium

   b) Unstable equilibrium

   c) Absolute equilibrium

   d) Local equilibrium

   Solution: b

6. During World War II, a heavy bomber was flying with an altitude of 9000m. Two bombs were launched as launching the second bomb B_2, weighted 0.5 Ton, preceded launching the first bomb $B1$, weighted 1 Ton. Consider that the two bombs were in a free fall motion and ignore air resistance. What's the vertical distance between the two bombs after 30 seconds from launching B_2 .

   a) $6542m$

b) $5525m$

c) $8237m$

d) $3827m$

Solution: d

$$\frac{1}{2}g(11+30)^2 - \frac{1}{2}g(30)^2 = 3827m$$

7. If some variables a,b,c and,d are related through the equation: $ab = cd$ where a is measured in Pa, b in J, and c in N^2. Find the SI unit of d.

a) m

b) m^2

c) m^{-1}

d) m^{-2}

Solution: c

8. If the vector $\overrightarrow{Y}$ = (17i + 3j + 9k) what are its angles with x, y and z axes respectively?

a) 29.16°, 81.14°, 62.46°

b) 29.16°, 62.46°, 81.14°,

c) 41.13°, 8.75°, 24.81 °

d) 41.13°, 24.81 °, 8.75°

Solution: a

The angle between two vectors follows this formula

$$cos\theta = \frac{\overrightarrow{Y} \cdot u}{|\overrightarrow{Y}||u|}$$

Here the second vector (u) is a unit vector that represents the axes. So, the angle with respect to the x-axis is

$$cos\theta_x = \frac{\overrightarrow{Y} \cdot i}{|\overrightarrow{Y}|} = \frac{17}{\sqrt{379}}$$

Which means $\theta_x = 29.16°$. Following the same method with other axes option that (a) is the correct answer.

9. An object is standing on the earth surface and is affected by its gravity. which of the following is correct:

a) the object attracts the Earth with a force bigger than the Earth attract the object.

b) the Earth attracts the object with a force bigger than the object attracts the Earth.

c) the Earth and the object attract each other with equal forces in magnitude.

d) the Earth attracts the object while the object doesn't attract the Earth.

Solution: c

10. Imagine you left your car outside on a freezing winter night, and the water inside the engine block froze solid. Given that water expands by about nine percent when it freezes, what would be the resulting pressure increase inside the engine block? (Given: The bulk modulus of ice is 2.0×10^9 Pa, and 1 atm = 760 Torr.)

a) 1368000 Torr

b) 18000 atm

c) 1.8×10^{10} Pa

d) 144400 mmHg

Solution: a

11. If a long, thin rod with rotation axis through center with a length of L and a rectangular plate of dimensions a, b have the same moment of inertia then:

a) $L^2 = (a + b)^2$

b) $L = (a + b)$

c) $L - 2ab = (a + b)^2$

d) $L + 2ab = (a + b)^2$

Solution: d

12. What is the period- to the nearest number of hours- of rotating around a star of mass 6×10^{20} kg in an ellipse that has semi-major axis of 1000 km?

a) 8

b) 9

c) 10

d) 11

Solution: b

13. Imagine two cars racing on a road. The distance between their paths is d_2. As you watch from the side of the road, your view of the second car is obstructed by the first car, which is a distance d_1 away from you. The velocity of the second car is v_2. Determine the equation that correctly represents the velocity of the first car v_1.

a) $v_1 = \frac{d_1+d_2}{d_1} \cdot v_2 m/s$

b) $v_1 = \frac{d_1+d_2}{d_2} \cdot v_2 m/s$

c) $v_1 = \frac{d_1}{d_1+d_2} \cdot v_2 m/s$

d) $v_1 = \frac{d_2}{d_1+d_2} \cdot v_2 m/s$

Solution: c

14. A projectile starts its motion with a velocity $v_i = 20m/s$ at an angle of $\theta = 30°$ with the horizontal. The function that represents the position of the projectile at any time t is:

a) $\vec{p}(t) = 10\sqrt{3}t\hat{i} + (10t - 4.9t^2)\hat{j}$

b) $\vec{p}(t) = (10t - 4.9t^2)\hat{i} + 10\sqrt{3}t\hat{j}$

c) $\vec{p}(t) = (10t + 4.9t^2)\hat{i} + 10\sqrt{3}t\hat{j}$

d) $\vec{p}(t) = 10\sqrt{3}t\hat{i} + (10t + 4.9t^2)\hat{j}$

Solution: a

15. A disk of radius R and mass M is rolling on a smooth horizontal surface without slipping with a linear speed v. What is the total kinetic energy of that disk?

a) $\frac{1}{2}Mv^2$

b) $\frac{1}{2}I\omega^2$

c) $\frac{3}{4}Mv^2$

d) $\frac{3}{4}I\omega^2$

Solution: c

An object rolling without slipping represents a perfect interpretation of both rotational and translational motion, so its total kinetic energy is the sum of both its rotational and translational kinetic energies.

$$KE_{trans} = \frac{1}{2}Mv^2$$

For a disk rotating about its center, its moment of inertia is $\frac{1}{2}MR^2$. Since angular velocity is related to the translational speed via $\omega = \frac{v}{R}$, the disks rotational kinetic energy is given by:

$$KE_{rot} = \frac{1}{2}I\omega^2 = \frac{1}{2}(\frac{1}{2}MR^2)(\frac{v^2}{R^2}) = \frac{1}{4}Mv^2$$

$$KE_{total} = KE_{rot} + KE_{trans} = \frac{1}{4}Mv^2 + \frac{1}{2}Mv^2 = \frac{3}{4}Mv^2$$

16. An ice skater is spinning with her arms extended. She suddenly shrinks her arms reducing her moment of inertia by half. WHat happens to her kinetic energy?

a) halves

b) stays the same

c) doubles

d) quadruples

Solution: c

Considering the conservation angular momentum:

$$L = I_{initial}\omega_{initial} = I_{final}\omega_{final}$$

Since, $I_{final} = \frac{I_{initial}}{2}$

$$I_{initial}\omega_{initial} = \frac{I_{initial}}{2}\omega_{final}$$

Solving for ω_{final}:

$$\omega_{final} = 2\omega_{initial}$$

The initial rotational kinetic energy was: $\frac{1}{2}I_{initial}\omega_{initial}^2$ The final rotational kinetic energy is: $\frac{1}{2}I_{final}\omega_{final}^2$ Substituting $I_{final} = \frac{I_{initial}}{2}$ and $\omega_{final} = 2\omega_{initial}$:

$$KE_{final} = \frac{1}{2}(\frac{I_{initial}}{2})(2\omega_{initial})^2$$

$$KE_{final} = \frac{1}{2}(\frac{I_{initial}}{2})4\omega_{initial}^2$$

$$KE_{final} = 2 \cdot \frac{1}{2}I_{initial}\omega_{initial}^2$$

substitute by $KE_{initial} = \frac{1}{2}I_{initial}\omega_{initial}^2$

$$KE_{final} = 2KE_{initial}$$

So the answer is that it doubles.

17. What is the correct sentence about lateral and longitudinal strains?

a) Longitudinal strain is the change in the body length while lateral strain is the change in the diameter according to the applied force.

b) Longitudinal strain is the angular change in the height of an object while lateral strain is the change in the lateral area of an object according to the applied force.

c) Longitudinal strain is the angular change in the height of an object while lateral strain is the change in the lateral area of an object according to the applied force.

d) Longitudinal strain is specified for tensile deformation and lateral strain is specified for compressive deformation.

Solution: a

18. What happens to a pulse on a string when collides with a fixed object like a wall?

a) Totally reflected but not inverted.

b) Totally reflected and inverted.

c) Isn't reflected nor inverted.

d) Isn't reflected but inverted.

Solution: b

19. A 800-gram block is placed at the end of a spring with a spring's constant of 5.00 N/m is free to oscillate on a frictionless, horizontal surface. What is the period of the system?

a) 2.51

b) 5.21

c) 1.52

d) 1.25

Solution: a

First, we need to find the angular frequency using this formula

$$\omega = \sqrt{\frac{K}{m}} = \sqrt{\frac{5}{0.8}} = 2.50 rad/s$$

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{2.50} = 2.51 sec$$

20. Given that the acceleration due to gravity on the Moon is less than that on Earth, where would the period of an identical pendulum be the shortest?

(a) On the Moon

(b) On Earth

(c) Cannot be determined due to insufficient data

(d) None of the above

Solution: b

21. A 5 kg block connected to a spring with a spring constant of 159.75 N/m is pulled to a position x = 3 m. Assuming that the block is on a frictionless horizontal surface, find the acceleration of the body.

a) -23.97 m/s^2

b) -958.5 m/s^2

c) -95.85 m/s^2

d) -2396 m/s^2

Solution: c

Solution:

$$\Sigma F_x = ma_x$$

$$-kx = ma_x$$

$$-159.75 \times 3 = 5a_x$$

$$a_x = \frac{-159.75 \times 3}{5}$$

$$a_x = -95.85 m/s^2$$

22. What is the speed of sound in the air at temperature $320°K$?

a) 348.28m/s

b) 358.28m/s

c) 368.28m/s

d) 378.28m/s

Solution: b

This formula calculates the speed of sound in the air according to the temperature:

$$v = 331\sqrt{1 + \frac{T_C}{273}}$$

Where T_C is the temperature in Celsius. So, by converting $320°K$ into Celsius and substituting, v is found to be 358.28m/s.

23. Consider two springs connected in series that were then all together connected to another spring in parallel. If all the springs have the same spring constant $k = 250N/m$, what is the equivalent displacement for the system of springs if it was subjected to a force of $F = 750N$?

a) 1 m

b) 2 m

c) 3 m

d) 4 m

Solution: b

The equivalent resistance of two mechanical springs connected in series is calculated through the formula:

$$\frac{1}{k_{series}} = \frac{1}{k_1} + \frac{1}{k_2}$$

$$\frac{1}{k_{series}} = \frac{1}{250} + \frac{1}{250} = \frac{1}{125}$$

$$k_{series} = 125N/m$$

The equivalent resistance of two mechanical springs connected in parallel is calculated through the formula:

$$k_{parallel} = k_1 + k_2$$

$$k_{eq} = 125 + 250 = 375N/m$$

According to Hooke's law:

$$F = k_{eq}x_{eq}$$

$$750 = 375x_{eq}$$

$$x_{eq} = 2m$$

24. A factory worker fainted while he was transferring some sort of appliance. His wife was there and she started screaming until an ambulance car came to rescue him. Initially, the ambulance car is moving with a velocity 28 m/s towards her while playing its alarm. Therefore, considering that the alarm is the source and the woman is the observer and the velocity of the sound is 343 m/s, the ratio between the frequency of the alarm sound and the screaming voice of the woman is . . .

    a) $\frac{45}{49}$

    b) $\frac{49}{45}$

    c) $\frac{54}{94}$

    d) $\frac{94}{54}$

Solution: a

$$f_o = f_s(\frac{v + v_o}{v - v_s})$$
$$\frac{f_s}{f_o} = \frac{v - v_s}{v + v_o}$$
$$\frac{f_s}{f_o} = \frac{343 - 28}{343 + 0}$$
$$\frac{f_s}{f_o} = \frac{45}{49}$$

25. An unknown rogue planet X has a mass of $M = 1.303 \times 10^{22} kg$ and a radius of $R = 1.188 \times 10^6 m$. What is the period of a simple pendulum of length $L = 1m$ that is suspended at a point 4000 meters above the planet's surface?

    a) 8.03

    b) 8.00

    c) 9.03

    d) 10.00

Solution: a

1- Calculate the gravitational field on that point:

$$g' = \frac{GM}{(R + h)^2}$$
$$g' = \frac{6.67430 \times 10^{-11} \times 1.303 \times 10^{22}}{(1.188 \times 10^6)^2}$$
$$g' \approx 0.612 m/s^2$$

2- Calculate the period of the pendulum

$$T = 2\pi\sqrt{\frac{L}{g'}}$$
$$T = 2\pi\sqrt{\frac{1}{0.612}}$$
$$T \approx 8.03 seconds$$

26. An adiabatic process is a type of thermodynamic process when

    a) the volume is constant

    b) the pressure is constant

c) the heat transfer equals zero

d) the heat transfer is constant

Solution: c

27. What is NOT a consequence of increasing the temperature?

a) Increase in the volume of a liquid

b) Increase in in the area of a solid

c) Decrease in the volume of of a gas at a constant pressure

d) Decrease in the density of a gas at a constant pressure

Solution: c

28. A sample of an ideal gas is heated, causing its temperature to double. What happens to the average speed of the molecules in the sample?

a) It quadruples.

b) It doubles.

c) It halves.

d) None of the above

Solution: d

29. A cube of ice with a mass of 90.0 g is floating in 500 g of water under 0^oC. Then, a piece of iron, with a mass of 2.0 kg, specific heat of 448 J/kg^oC, and temperature 100^oC. Assuming that the ice-water-iron system is an isolated system and chemical reactions occur in it, what's its final temperature? Know that the latent heat of fusion of water is $3.33 \times 10^5\ J/kg$, and the specific heat of water is 4186 J/kg^oC.

a) 5.72^oC

b) 19.95^oC

c) 25.32^oC

d) 50.981^oC

Solution: b

$$Q_{cold} = -Q_{hot} \implies m_{ice}L_f + m_{water}c_{water}(T_f - 0) = m_{iron}c_{iron}(100 - T_f)$$

$$m_{ice}L_f = 100m_{iron}c_{iron} - m_{iron}c_{iron}T_f - m_{water}c_{water}T_f$$

$$m_{ice}L_f - 100m_{iron}c_{iron} = -T_f\left(m_{iron}c_{iron} + m_{water}c_{water}\right)$$

$$T_f = \frac{100 m_{iron} c_{iron} - m_{ice} L_f}{m_{iron} c_{iron} + m_{water} c_{water}} = 19.95^o C$$

30. If a Carnot engine has T_h = 380K and T_c = 130K, what is the efficiency of this engine in percentage?

    a) 35.79%

    b) 45.79%

    c) 55.79%

    d) 65.79%

    Solution: d

    Carnot engine efficiency is calculated with the formula:

    $$e_c = 1 - \frac{T_c}{T_h}$$

    That will output 0.6579 for this case, and multiplying this output by 100 will option the efficiency in percentage.

31. In a late night, one of IPhR's problem authors was hungry. He decided to warm some of the lunch leftovers. He used the microwave to get that job done. Given that area of the surface of the microwave emitting the electromagnetic radiations is given to be 1200 cm^2, the temperature of the surface is 333.15 K and σ is equivalent $5.6696 \times 10^{-8} W/m^2 \cdot K^4$, calculate the power of the electromagnetic waves radiated from the surface. (Assuming that the microwave is a black body)

    a) 8380.9 W

    b) 83.8 W

    c) 5.523 $\times 10^{19}$ W

    d) 55.2 $\times 10^{-19}$ W

    Solution: b

    Solution: Stefan's Law

    $$P = \sigma A e T^4$$

    $$P = 5.6696 \times 10^{-8} \cdot 1200 \times 10^{-4} \cdot 1 \cdot (333.15)^4$$

    $$P = 83.8W$$

32. A 100 kPa methane has a 150 cm^3 volume at 25 degrees Celsius. When the temperature rose up to 125 degrees Celsius, what was the pressure of the methane? (Assuming that the volume changes were negligible)

    a) 74.88 kPa

b) 167.50 kPa

c) 59.70 kPa

d) 133.54 kPa

Solution: d

$$PV = nRT$$

$$\frac{P_i}{T_i} = \frac{P_f}{T_f}$$

$$P_f = \frac{P_i \times T_f}{T_i}$$

$$P_f = \frac{100 \times (125 + 273.15)}{(25 + 273.15)}$$

$$P_f = 133.54kPa$$

33. A spherical surface encloses a point charge located at its center. If the charge is doubled and the radius of the surface is also doubled, what are the effects on the electric flux (Φ_E) through the surface and the magnitude of the electric field (E) at the surface?

a) Φ_E does not change and E does not change.

b) Φ_E decreases and E increases.

c) Φ_E increases and E decreases.

d) Φ_E increases and E increases.

Solution: c

34. What's the drift speed of the electrons in a circular copper wire with radius $r = 10mm$ carrying a continuous current of $I = 5A$ with an electron density of $n = 5.37 \times 10^{27}$?

a) $1.67 \times 10^{-6} m/s$

b) $1.67 \times 10^{-5} m/s$

c) $1.85 \times 10^{-5} m/s$

d) $1.85 \times 10^{-6} m/s$

Solution: c

The current in a wire of cross-section A and charge carriers density n is given by:

$$I_{avg} = nqAv_d$$

Solving for the drift velocity

$$v_d = \frac{I_a vg}{nqA} = \frac{5}{5.37\times10^{27}\cdot1.60\times10^{-19}\cdot(10\times10{-}3)^2\pi} = 1.67\times10^{-5}m/s$$

35. Which of the following DC-supplied circuits can the current oscillate in?

    I. RC-circuit

    II. RL-circuit

    III. LC circuit

    IV. RLC circuit

    a) I and III

    b) II and IV

    c) I and II

    d) III and IV

    Solution: d

36. What is the formula for the impedance in a parallel RLC circuit powered by an AC power source?

    a) $\left[R^2+(X_L-X_C)^2\right]^{\frac{1}{2}}$

    b) $\left[\frac{1}{R^2}+\left(\frac{1}{X_L}-\frac{1}{X_C}\right)^2\right]^{-\frac{1}{2}}$

    c) $\left[R^2+(X_L-X_C)^2\right]^2$

    d) $\left[\frac{1}{R^2}+\left(\frac{1}{X_L}-\frac{1}{X_C}\right)^2\right]^{-2}$

    Solution: b

37. When a current-carrying conductor is placed in a magnetic field, a potential difference is generated between two points lying along a direction perpendicular to both the current and the magnetic field. Which of the following is related to this article?

    a) Hall effect

    b) Ampere's law

    c) Columbus observations

    d) Faraday's law

    Solution: a

38. 2 resistors, with resistance R_1 *and* R_2 , 2 capacitors, with capacitance C_1 *and* C_2, and 2 inductors, with inuctance L_1 *and* L_2, are connected in parallel to each other in three different circuits (i.e. each similar

electric component are in one of the 3 circuits.) Then find the expression for the equivalent resistance, capacitance, and inductance in the ciruits.

a) $\left(\frac{R_1R_2}{R_1+R_2}\right)$, $\left(\frac{C_1C_2}{C_1+C_2}\right)$, $\left(\frac{L_1L_2}{L_1+L_2}\right)$

b) (R_1+R_2), (C_1+C_2), (L_1+L_2)

c) (R_1+R_2), $\left(\frac{C_1C_2}{C_1+C_2}\right)$, (L_1+L_2)

d) $\left(\frac{R_1R_2}{R_1+R_2}\right)$, (C_1+C_2), $\left(\frac{L_1L_2}{L_1+L_2}\right)$

Solution: d

39. A circular metallic ring of cross-sectional area $5\times10^{-4}m^2$ whose plane is perpendicular to a uniform magnetic field of flux density 0.3 T, if it is rotated by an angle of 45 degrees about an axis perpendicular to the direction of the field within 0.2 s. what is the magnitude of the average induced emf through this period?

a) 3.8×10^{-4}

b) 1.9×10^{-4}

c) 3.1×10^{-4}

d) 2.2×10^{-4}

Solution: d

We know that:

$$\Phi = BA\cos\theta$$

Where θ is the angle between the magnetic field and the plane normal to the plane of the circuit. We can calculate the induced emf:

$$\text{emf} = \text{N}\frac{\Delta\Phi}{\Delta t} = \frac{BA\cos\theta_2 - BA\cos\theta_1}{\Delta t} = \frac{0.3\times5\times10^{-4}\times(\cos45^\circ-\cos0^\circ)}{2} = 2.2\times10^{-4}\text{V}$$

40. A parallel-plate capacitor of width w, lengthℓ, and separation distance d. If the capacitor holds a charge Q. Find a mathematical expression for the electric energy stored in the capacitor in terms of the previous variables. Take the vacuum permittivity to be ϵ_0.

a) $\frac{Q^2d}{\epsilon_0w\ell}$

b) $\frac{Q^2w\ell}{\epsilon_0d}$

c) $\frac{Q^2d}{2\epsilon_0w\ell}$

d) $\frac{Q^2w\ell}{2\epsilon_0d}$

Solution: c

$$C = \frac{\epsilon_0A}{d} = \frac{\epsilon_0w\ell}{d}$$

$$U_E = \frac{Q^2}{2C} = \frac{Q^2 d}{2\epsilon_0 w \ell}$$

41. Given a 3-mF capacitor, a 4-mF capacitor, and a 5-mF capacitor, which of the following capacitance values cannot be achieved by using a combination of all three?

   a) $\frac{47}{9}$-mF

   b) $\frac{47}{7}$-mF

   c) $\frac{47}{60}$-mF

   d) $\frac{47}{8}$-mF

   Solution: c

42. In a semiconductor material, the ratio of the electron drift velocity to the applied electric field strength is known as the

   a) Electron mobility

   b) Electrical conductivity

   c) Electrical permittivity

   d) Dielectric constant

   Solution: a

43. An electron emitted at a speed of $v = 2 \times 10^7 m/s$ enters a homogeneous magnetic field of magnitude $B = 1.5 \times 10^{-3} T$ at point A making an angle $\theta = 30°$ with the magnetic field vector. What is the distance from point A where the electron again crosses the field line that passes through A.

   a) $0.51m$

   b) $0.41m$

   c) $1.51m$

   d) $1.41m$

   Solution: b

   The movement of an electron entering a magnetic field making an angle with the magnetic field vector is described with a helix trajectory where the component of the velocity perpendicular to the magnetic field vector is responsible for the circular motion and the component parallel to the magnetic field vector is responsible for the linear motion along the axis.
   Resolving the two components of the velocity gives $v_x = \cos\theta$ and $v_y = \sin\theta$
   The Lorentz force is the one deriving the centripetal motion, so

$$q v_y B = \frac{m v_y^2}{r}$$

solving for the radius

$$r = \frac{mv_y}{qB}$$

The periodic time for the circular motion is given by

$$T = \frac{2\pi r}{v_y} = \frac{2\pi m}{qB}$$

The orbital time represents the time it takes for the electron to complete one rotation around its axis of rotation. Thus, crossing the same field line again. At the mean time, the electron travels a horizontal distance, parallel to the field line, that is given by

$$s = v_x \cdot T = v_x \frac{2\pi m}{qB} = 0.41m$$

44. The dielectric polarization by the capacitor electric field E produces an opposite electric field E_{ind} with another charge density σ_{ind}. Describe the relation between the capacitor charge density σ and σ_{ind} in terms of k, the dielectric constant.

    a) $\sigma_{ind} = \frac{\sigma}{k}$

    b) $\sigma_{ind} = k\sigma$

    c) $\sigma_{ind} = (\frac{k-1}{k})\sigma$

    d) $\sigma_{ind} = (k^2 - 1)\sigma$

    Solution: c

$$\sigma_{ind} = (\frac{k-1}{k})\sigma$$

45. An IPhR Problem Author bought three cylindrical conductors made from the same material. The ratio between their lengths and masses are 1:4:9 and 2:3:5 respectively. Which one should he use to get the least resistance?

    a) 1:3:5

    b) 27:4:9

    c) 10:50:3

    d) 15:160:486

Solution: d

To avoid confusion, we will use ρ for the resistivity of the material of the cylindrical conductors and D for the density of the cylindrical conductors. Notice that

$$D = \frac{M}{V} \implies M = D \cdot V = D \cdot Al \implies A = \frac{M}{Dl}$$
$$R = \rho \frac{l}{A} = \rho D \frac{l^2}{M}$$
$$\implies R_1 = \rho D \cdot \frac{1^2}{2} = \frac{1}{2}\rho D$$
$$\implies R_2 = \rho D \cdot \frac{4^2}{3} = \frac{16}{3}\rho D$$
$$\implies R_3 = \rho D \cdot \frac{9^2}{5} = \frac{81}{5}\rho D$$
$$\implies R_1 : R_2 : R_3 = 15 : 160 : 486$$

46. IPhR Problem Author wanted to craft new lenses. Because of his nearsightedness, a 3 cm far object appears to him as 4 cm far. Accordingly, what should be the focal length of his lens?

    a) 0.023 *cm*

    b) 0.017 *cm*

    c) 2.3 *cm*

    d) 1.7 *cm*

    Solution: d

    Solution. Using the lens equation:

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o} = \frac{1}{3} + \frac{1}{4} \implies f = 1.7\ cm$$

47. Two plane wavefronts of light, one incident on a thin convex lens and another on the refracting face of a thin prism. After refraction at them, the emerging wavefronts respectively become

    a) Plane wavefront and spherical converging wavefront

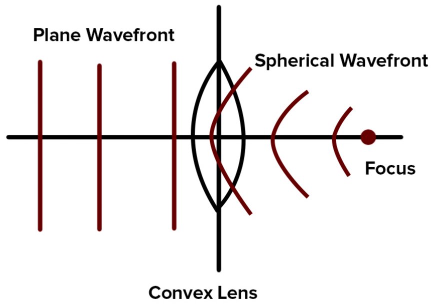
    b) Plane wavefront and spherical diverging wavefront

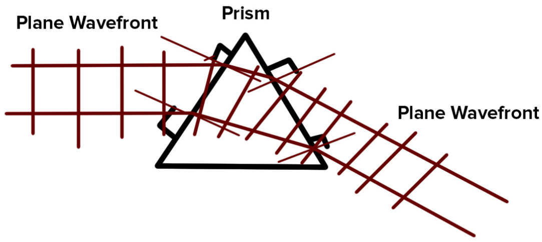
    c) Spherical converging wavefront and plane wavefront

    d) Spherical converging wavefront and spherical diverging wavefront

    Solution: c

    The emerging wavefront from a convex lens will be spherical converging and the emerging wavefront form the prism will be a Plane wavefront.





48. A monochromatic light source, source emitting light of a single wavelength and color, illuminates a single slit of width $a = 0.5mm$ the second minimum of the diffraction pattern was observed at an angle of 2.6×10^{-3} radians on the screen. What is the wavelength λ of the light used?

    a) 650 nm

    b) 550 nm

    c) 450 nm

    d) 350 nm

    Solution: a

    The single slit diffraction formula for dark fringes is given by:

    $$a \sin \theta_D ark = m\lambda$$

    Where a is the width of the slit, $\theta_D ark$ is the angle between the normal of the slit and the dark fringe,m is the order of the fringe, and λ is the wavelength of the diffracted light.

    Plugging the values and solving for λ gives $\lambda = 650nm$

49. A light ray traveling in air is incident on the left side of the cylinder. The incident light ray and outgoing "exiting" light ray are parallel, and d = 2.00 m. Determine the index of refraction of the material at which the radius of the cylinder R = 2.00 m and the point of reflection is collinear to the diameter. If the speed of the incident light ray equals 3 what is the speed of the outgoing ray?[$n_{of\ the\ air} \approx 1$]

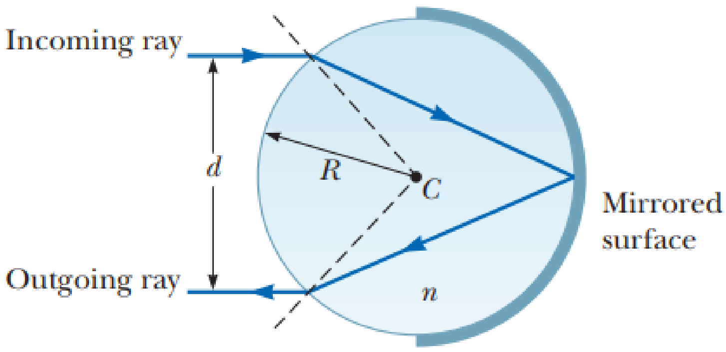


Figure 1

a) 1.74, 3.0 m/sec

b) 1.74, 1.55 m/sec

c) 1.93, 3 m/sec

d) 1.93, 1.55 m/sec

Solution: c

Solution

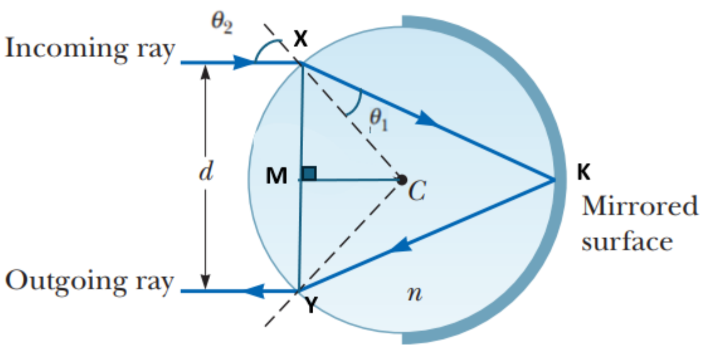


Figure 2

to calculate the index, we have to find θ_1.and θ_2

$$sin(\angle XCM) = \frac{MX}{CX} = \frac{1}{2}$$

$$m(\angle XCM) = 30°,\ m(\angle XCY) = 60°,\ m(\angle CXY) = m(\angle CYX) = 60°$$

since $\angle XKY$ is an inscribed angle.

$$m(\angle XKY) = \frac{m(\angle XCY)}{2} = 30°$$

$$m(\angle KXY) = m(\angle KYX) = 75°$$

$$\theta_1 = 75 - 60 = 15^\circ$$

$$\theta_2 = 180 - (90 + 60) = 30^\circ$$

using Snell's law:

$$n_{cylinder} \times sin(\theta_1) = n_{air} \times sin(\theta_2)$$

$$1 \times sin(30) = n_{cylinder} \times sin(15)$$

$$n_{cylinder} = \frac{sin(30)}{sin(15)} = 1.93 \tag{1}$$

2- The speed of the light will remain the same as the incident ray and the outgoing ray both move in the same medium so, the answer is **3 m/ sec**.

50. IPhR Problem Author was driving his Audi Q8 when he noticed that his side mirror was defective. The magnification power of the mirror was $\frac{1}{2}$, when it should be $\frac{1}{3}$. Accordingly, he decided to make some adjustments to the focal length of the mirror. What would be the ratio of the final focal length f_2 to the initial focal length f_1?

    a) $\frac{1}{8}$

    b) $\frac{3}{2}$

    c) $\frac{3}{4}$

    d) $\frac{2}{3}$

    Solution: c

    Solution. Let p be the distance between the mirror and some fixed object, q_1 be the distance between the image of the object and the mirror with its initial focal length, and q_2 be the distance between the image of the object and the mirror with its final focal length. The magnification power in case of its initial focal length can be expressed as follows.

$$M_1 = \frac{1}{2} \implies \frac{-q_1}{p} = \frac{1}{2} \implies p = -2q_1$$
$$\implies \frac{1}{p} + \frac{1}{q_1} = \frac{1}{f_1} \implies \frac{1}{-2q_1} + \frac{1}{q_1} = \frac{1}{f_1}$$
$$\implies f_1 = 2q_1$$

The magnification power in case of its final focal length can be expressed as follows.

$$M_2 = \frac{1}{3} \implies \frac{-q_2}{p} = \frac{1}{3} \implies p = -3q_2$$
$$\implies \frac{1}{p} + \frac{1}{q_2} = \frac{1}{f_2} \implies \frac{1}{-3q_2} + \frac{1}{q_2} = \frac{1}{f_2} \implies f_2 = \frac{3q_1}{2}$$
$$\implies \frac{f_2}{f_1} = \frac{\frac{3q_1}{2}}{2q_1} = \frac{3}{4}$$

51. If light travels from 1,1,1-trichloroethane, an organic solvent, to water with angle of incidence with certain degrees and came out to water making an angle of 36 degrees which is complementary to the angle of refraction. Given that the index of refraction of both water and 1,1,1-trichloroethane are 1.333 and 1.438 respectively. Find the velocity of light in 1,1,1-trichloroethane.

    a) $4.54 \times 10^8 m/s$

    b) $6.33 \times 10^8 m/s$

    c) $3.97 \times 10^8 m/s$

    d) $2.36 \times 10^8 m/s$

    Solution: d

    First, to get the velocity of the light in the velocity of light in 1,1,1-trichloroethane, we can use the following equation:

$$\frac{sin\theta_2}{sin\theta_1} = \frac{v_2}{v_1} \tag{2}$$

But we should first get the velocity of light in water as follows:

$$v = \frac{c}{n}$$

$$v = \frac{3.00 \times 10^8}{1.333}$$

$$v_2 = 2.55 \times 10^8 m/s \tag{3}$$

Then, using Snell's law of refraction, we can get the angle of incidence as follows:

$$n_1 sin\theta_1 = n_2 sin\theta_2$$

$$sin\theta_1 = \frac{n_2 sin\theta_2}{n_1}$$

$$sin\theta_1 = \frac{1.333 \times sin(90-36)}{1.438} \rightarrow sin\theta_1 = 0.75 \tag{4}$$

Finally, substituting with (2) and (3) in (1), we get the following:

$$v_1 = \frac{v_2 sin\theta_1}{sin\theta_2}$$

$$v_1 = \frac{2.55 \times 10^8 \times 0.75}{sin(90-36)}$$

$$v_1 = 2.36398 \times 10^8 m/s$$

52. A box of two mirror faces is moving with some velocity V and contains a light beam that oscillates vertically between the mirrors for an observer in the frame of the moving box. Consider the height of the box equals d so what is the time required for a beam oscillation measured by an observer at rest relative to the box?

a) $\frac{d}{c}$

b) $\frac{2d}{c}$

c) $\frac{2dc}{\sqrt{1-\frac{v^2}{c^2}}}$

d) $\frac{2d}{c\sqrt{1-\frac{v^2}{c^2}}}$

Solution: d

Proper time or t_p is measured by the observer in the box frame to be equal $\frac{2d}{c}$. The time measured by the observer at rest = $\dfrac{t_p}{\sqrt{1-\frac{v^2}{C^2}}} = \dfrac{2d}{c\sqrt{1-\frac{v^2}{c^2}}}$

53. Consider a pure-silicon semiconductor in which the concentration of free electrons is $10^{15}cm^{-3}$. If the semiconductor is doped with some material in which the concentration of free electrons became $10^{9}cm^{-3}$, what is the concentration of the holes in the new semiconductor?

a) $10^{15}cm^{-3}$

b) $10^{20}cm^{-3}$

c) $10^{27}m^{-3}$

d) $10^{36}m^{-3}$

Solution: c

$$np = n_i^2 \rightarrow p = \frac{n_i^2}{n} \rightarrow p = \frac{10^{30}}{10^9} = 10^{21}cm^{-3}$$

$$10^{21}cm^{-3} = 10^{21}cm^{-3} \times \frac{100^3 cm^3}{1m^3} = 10^{27}m^{-3}$$

54. In the Avengers Endgame final battle, Captain Marvel showed up from space with her maximum speed to fight Thanos, the mad titan. When she was flying, Carol noticed that Antman's suit with his giant the form has a yellow (600nm) color, but when she stopped she saw him in his true red color (700nm). What was Captain Marvel's velocity?

a) $2.31 \times 10^4\ m/s$

b) $3.54 \times 10^5\ m/s$

c) $4.59 \times 10^7\ m/s$

d) $7.22 \times 10^7\ m/s$

Solution: c

Recall the relativistic Doppler's effect formula for frequency.

$$f' = \frac{\sqrt{1+\frac{v}{c}}}{\sqrt{1-\frac{v}{c}}} f$$

$$\because f = \frac{v}{\lambda}$$

$$\therefore \frac{\lambda'}{\lambda} = \frac{\sqrt{1 - \frac{v}{c}}}{\sqrt{1 + \frac{v}{c}}}$$

$$\implies \frac{600}{700} = \frac{\sqrt{1 - \frac{v}{3\times10^8}}}{\sqrt{1 + \frac{v}{3\times10^8}}}$$

$$\implies v \approx 4.59 \times 10^7 \ m/s$$